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INSTRUCTIONS FOR RESERVOIR SEDIMENTATION SURVEYS

by

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Head, Section of Sedimentation Studies

Revised January 1, 1936 by

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INSTRUCTIONS FOR RESERVOIR SEDIMENTATION SURVEYS

PURPOSE

The immediate objective of each survey will be determination of the volume and distribution of sediment accumulated within the original storage basin of the reservoir during a specific period of time, either the entire period of the reservoir's existence or a shorter period between an earlier and the current resurvey.

The ultimate objectives are first, to establish information on the factors involved in reservoir silting, the rates of silting, the effects of different soil, slope, and climatic conditions, and to correlate these results with land use in the drainage area; and second, to develop new methods of silt control supplementary to existing erosion control practices.

GENERAL PLAN OF SURVEY

Survey operations, in all cases, will be designed to establish accurate basic data and field layout to facilitate future resurveys, as well as to check previous surveys and indicate past rates of silting.

The exact plan of field work will depend upon choice of surveying methods, but will include under different conditions primary triangulation control, areal and topographic mapping, range location, sounding and leveling range cross-sections, and direct measurement of silt deposits.

Office work will include preparation of a reservoir map, showing results of field work, plotting and planimetering cross-sections, com-

putation of original capacity and silt volumes, and preparation of a project report.

CHOICE OF RESERVOIRS

Choice of reservoirs for survey will be based on a state by state reconnaissance of the nation now in progress. Factors to be considered are original storage capacity per square mile of drainage area in relation to annual rainfall, distinctiveness and character of drainage area, amount of sediment, availability of previous base maps and cooperation of owners.

Recommendations of reservoirs for detailed survey and recommendation of the program to be followed will be submitted by the geologist in charge of reconnaissance, but final choice and approval will be made by the Washington office.

CHOICE OF SURVEY METHODS

Choice of methods to be followed in making the detailed survey will depend on the amount and distribution of sediment as indicated by reconnaissance, and on the availability and character of previous base maps.

Silt volume and distribution may be derived by mapping contours on the present silt surface over the entire lake, by establishing sounding and measuring silt depth on ranges, or by a combination of the two methods. Choice of methods will depend on the following conditions:

Contour Method

The principal advantage of the contour method is that it shows

both the vertical and horizontal distribution of silt and allows plotting of capacity curves. On the other hand, it generally necessitates a longer period of survey and increases the probable error unless the original basin maps are known to be of a high standard of accuracy.

The contour method can be used only where accurate base maps on suitable scale with contour interval not over 10 feet are available. Contouring should not be resorted to on those portions of lake where penetration with spud may be universally obtained, providing those portions of the lake amount to 50 percent or more of the total area of the original basin.

Range Method

The range method has the advantage of speeding the time of survey and of allowing actual silt thickness measurements. It is to be used where more than 50 percent of the lake area is covered by silt which can be penetrated with sampling spud. In the absence of contour maps, it may be used on the deltas if original cross-sections can be established by borings or from known elevations in the old valley.

Combination of Ranges and Contours

A combination of the two methods will probably be applicable to a majority of reservoirs surveyed. It will consist of setting up and measuring ranges over the lower part of the lake where penetrations are generally obtainable and mapping contours on the delta portions of the lake, providing previous contour maps are available for comparison. Previous maps will be checked by well distributed borings wherever possible.

RANGE METHOD

Primary Control

Primary control is to be established on all lakes where adequate previous base maps are not available. Where maps of suitable scale showing accurate crest line contour can be obtained, ranges may be tied together by stadia control with frequent reference lines to prominent points shown on the maps, such as bench marks, property corners, bridges, houses, junction of streams or conspicuous irregularities of contours. Observed errors in previous maps especially in shore line should, however, be corrected by remapping, using adjacent correct points for control.

Primary control may be used for establishing ranges where distances are so great that stadia readings cannot be made.

Primary control, where it is deemed advisable, will be established by planetable triangulation, starting from a chained and rechecked base line, and will be further checked by chain measurement between located points in the outer reaches of each major extension of the primary network.

Scales of primary triangulation will be adjusted to size of the reservoir with a view to facilitating progress and keeping the number of field sheets within practical limits. On reservoirs a mile or two long, a scale of 1 inch = 100 feet to 1 inch = 400 feet will serve. On larger reservoirs scales of 1 inch = 500 feet to 1 inch = 1000 feet should be used.

Base lines 2000 to 5000 feet long according to scale of the map

are preferable to shorter lines. Where possible base lines should be as long as the greatest distance between any two adjacent or opposite triangulation stations.

Secondary Control

Secondary control will be tied to primary triangulation stations where they have been established or otherwise to well referenced features shown on the map. It will be extended by stadia shots or traverse depending on fore and backsight orientation of the board. In small bays or narrow winding lake arms that involve no great distances, magnetic orientation may be permitted locally, using a magnetic line drawn at the last backsight control station.

The principal use of secondary control in the range method will be for mapping shore line.

Range Location

Where the range method is applicable, the main body of the lake and its principal arms will be subdivided by cross ranges so that each subdivision will present about the same silted condition as occurs on the bordering ranges.

The ranges should extend rather directly across the lake from shore to shore where it is practicable, but of greater importance is the need for having the upstream and downstream ranges approximately parallel. A divergence of not more than 10° may be tolerated for convenience in locating the ranges, but not more than 30° should be permitted in any case except as stated below. The series of ranges

on the main body of the lake should begin with an initial range just above the dam, or on the arms directly across the mouth, and should extend upstream to its head or to a final cross range below the delta area to be mapped in detail by contours.

Frequently there will be bends or curves in the reservoir that will render the maintenance of the above limit of divergence for the entire series impracticable. In such cases the series is to be broken up into sets where the limit of divergence is maintained within each set. In the segment between the sets the ranges may have any divergence not greater than 90°. In these transition segments it is desirable to have the end ranges set close together, or even starting from a common point, the purpose being to concentrate the irregularity so that it will have the least effect.

Where a tributary enters or an arm of the lake is cut off, a new series of ranges is started without regard to the direction of the two main ranges of the segment. The first range should be across the mouth of the tributary and perpendicular to its general direction or as near to this position as practical considerations will permit.

Range Elevations

The elevation of each end point of a range must be established. Where the end point of the range is not more than 500 feet from the water's edge, the planetable may be used as a level in establishing this elevation. The elevation of the range end on the far side of the lake may be established by level or planetable on the near side provided the shots to the end point and the water level are neither more than 2000 feet long and the difference in the length of these two shots is not

than 200 feet. The difference between the two rod readings is added to the lake level to give the elevation of the range end.

If the range ends are far removed from water surface a level should be used to carry elevations to the range ends; and if an entire section of the reservoir basin is above backwater at the time of survey, level lines must be carried either from accurately determined water surface below the lower zone of flowage into the reservoir or from established bench marks known to be correct with respect to water elevation gages used for other parts of the lake.

Where water surface is used for elevations, the height of water should be obtained hourly to the nearest tenth of a foot. In most power reservoirs, a gage is located on the dam or powerhouse. In such cases arrangements should be made in advance with the operators in charge to furnish hourly height of water readings during field hours. In other cases, on many smaller lakes, it will be necessary to establish a temporary water gage. A simple type for field use can be made by graduating a long piece of lumber in feet and tenths and driving into the bottom of the lake near the dam or pier where the depth of water is greater than any possible drawdown in the lake during the course of survey. The gage should be tied by levels to a permanent B. M. if one is available in reasonable distance. Otherwise assume a datum for height of water at beginning of survey. With temporary gage it may be necessary to employ a local resident to take water readings hourly.

Range Profiles

Elevations on top of the silt will be taken along each range below water level at regular intervals by soundings. Elevations above water will be taken by levels up to the range end monument which must

be set above spillway stage.

Sounding intervals of about 20 feet are suitable on ranges up to 500 feet. On longer ranges with generally regular profile, intervals of 50 to 100 feet may be used without material increase in error.

Direct Measurement of Silt

Direct measurement of silt with sampling spud to the nearest tenth of a foot is to be made at intervals on all ranges so far as penetrations to the underlying basin soil can be gained.

Water depths are to be measured and recorded by sounding at each point of direct silt measurement. The elevation of old soil surface is to be computed from this depth and determined silt thickness, both below water and on exposed shore if the lake is drawn down below crest level.

Spud observations on ranges up to 500 feet long should be taken at intervals of 50 to 75 feet or with each second or third sounding. On ranges 500 to 1000 feet long, spuddings should be taken every 100 feet or with every fourth sounding. On ranges from 1000 to 2000 feet long, spuddings should be taken every 150 feet or with every fifth sounding. On longer ranges spuddings may be 200 feet or more apart. Spacing of spuddings will depend on silt conditions, and rigid rules need not be followed. The main object is to obtain a measurement with each appreciable change of silt depth. Thus spuddings should be closer together where the range crosses the original stream channel, and may be farther apart over broad flat areas. The edge of the silt toward each range end should be determined and located on the map either by probing with the spud or by search between the water's edge and range monument.

It will be found advantageous to take spuddings simultaneously with soundings on one trip across the range.

Use of Silt Sampler or Spud

The silt sampler or spud will be used on range or elsewhere only when the boat is stationary, held so either by the oarsman or by anchor.

The spud will be plunged from sufficient height to give penetration through the silt and slightly into the underlying original soil. The longer more slender spud will be used where deeper penetration is required.

Distinction between old soil and silt generally depends upon comparative softness and lack of grit in the silt. Often there is a clear difference in color. Where old soil is clayey it generally clings to the spud more stiffly than the silt; or where sandy, it may fail to come up on the spud so that a clean section of spud will mark the lower limit of the silt.

In many places silt contains leaf fragments that are absent from old soil or the old soil may contain roots and rootlets that are absent from the silt.

In the very deep water or where silts are gritty and the spud sample tends to wash off on way to surface, it may be advantageous to smear one side of the spud with ordinary automobile cup grease. This has been found efficient especially in retaining a sample of sand.

Measurement of Volume of Delta Deposits

Where deltas are present and original contour maps of the basin are available, the contour method described below is to be followed in surveying that portion of the lake or lake arm between the last range where silt penetration can be obtained and a point where backwater is confined entirely to the original channel.

Between the point where backwater is confined entirely to the original channel and the actual upper limit of backwater, ranges from bank to bank along the channel will give the present cross-section. The original cross-sections may be reconstructed from such data as are available, particularly original river profiles.

Where previous contour map of a present delta area is not available, a longitudinal section of the delta may be indicated by contouring the delta and adjacent portions of the valley and flooded area, supplemented by borings to old soil level at the head of the delta and spudding to old soil down the arm. With surface profile and original bottom profile known, the form and depth of the medial longitudinal section of the delta can be plotted.

If the valley be evenly spreading downstream from head to foot of the delta, the total volume can be closely approximated by dividing the area of the medial longitudinal section into two equal parts by a vertical line, measuring the length of the vertical line or depth of delta in feet and multiplying by this number of feet the area, in acres, of the delta surface upstream from this point to its head. The product is volume of the delta deposit in acre feet.

In more irregular valleys, and lacking original contour maps delta volumes will be difficult and uncertain of determination. An honest attempt by assembling a good contour map of present extent and configuration, supplemented by a reasonable amount of boring data is advisable to give a fair basis of practical estimate and also to establish a proper basis for future resurveys.

Plotting and Planimetering

Range profiles are to be plotted on cross-section paper ruled 10 squares to the inch. For most ranges a horizontal scale of 50 feet to the inch and a vertical scale of 5 feet to the inch will be satisfactory. In some more detailed work or with small silt thickness it may be necessary to use a vertical scale of 2 feet to the inch. On special cases, scales may be varied to fit a particular problem at hand.

The elevation of the silt surface, or the bottom where silt is absent, should be calculated for each point of sounding by subtracting the depth of water from the elevation of water surface during the hour of sounding, as obtained from gage readings.

The elevations calculated for each sounding are to be plotted as a profile cross-section of the range. Distances of soundings from one end of the range are scaled from the planetable sheet, reading to the nearest foot by use of a magnifying glass, and recorded in notebook. With distances and elevations recorded, the points are plotted, and are joined by straight line segments to form the range cross-section.

The elevation of the old soil at each point of spudding may be easily plotted after the silt surface cross-section is completed by plotting a point directly below the sounding equal to the silt thickness recorded. The thickness of silt between spud measurements is to be carefully interpolated by plotting half the difference in silt depth at a point halfway between spuddings again interpolated at midway intervals until the number of interpolated old soil elevations equals the number of soundings. Where the thickness of sediment requires boring by auger for penetration, the present surface may have little relation to the original surface, now buried, and in such cases interpolation should

not be done by rule of thumb, but rather in the light of circumstances, using all available data on original valley slopes and profiles to supplement boring data.

The area enclosed by the old soil or bottom curve up to crest level is to be obtained by planimeter in square feet. The area enclosed by the silt or upper curve up to crest level is measured in the same way. The difference in area represents area of silt. Results on the above scale; which should be accurate to within 200 square feet and will be recorded on each cross-section.

Range lengths for use in calculations are to be scaled from the cross-sections between shore lines which are taken as the points where the old soil curve crosses the spillway elevation contour. Ranges are to be carefully plotted on the base map and the range lengths, in feet, recorded on them. Where the range lengths do not agree with the distances between shore lines, the shore lines are to be adjusted, on the basis of field data, preferably by remapping.

The area enclosed by all ranges and intervening shore line bounding each segment of the lake is to be planimetered. The quadrilateral area, which is formed by the two main ranges and straight lines connecting the points where they intersect the shore lines, is then obtained by planimetering, or by scaling and computing. These areas will be converted into acres to the second decimal place and recorded on the base map, labeled A and A' respectively.

The planimeter work must be carefully done. At least four separate measurements must be made and averaged on each curve and segment for correct results.

Computation of Original Capacity and Silt Volume

The segments, or subdivisions of the lake may be bounded by any number of ranges and intervening stretches of shore line. Areas with two ranges may have one or two stretches of shore line and areas with three or more ranges may be closed figures with no shore line or may have any number of stretches up to the number of ranges.

The original capacity and silt volume for all segments except the one next to the dam will be computed by the following general formula:

$$V = \frac{A'}{3}\left(\frac{E_1 + E_2}{W_1 + W_2}\right) + \frac{A}{3}\left(\frac{E_1}{W_1} + \frac{E_2}{W_2}\right) + \frac{h_3 \; E_3 + h_4 \; E_4 + \ldots\ldots\ldots\ldots}{130{,}680}$$

where: V= Original Capacity or Silt Volume in acre-feet.

A'= The Quadrilateral Area, i. e., the area in acres of the quadrilateral formed by connecting the points of range intersection with crest contour between the two principal or most nearly parallel ranges.

A= The Lake Area of the segment in acre-feet.

E= The cross-sectional area, in square feet, of original capacity or silt volume cut by bounding range.

W= Width of bounding range at crest elevation in feet.

h= The Perpendicular distance from the range on a tributary to the junction of the tributary with the main stream, or if this junction is outside the segment, to the point where the thalweg of the tributary intersects the downstream range.

The subscripts to E, W, and h indicate the number of ranges with respect to the segment.

The formula is general and covers all cases except the special case of the segment next to the dam where the effect of the shape of the dam does not lend itself to inclusion in the formula. The application of the formula is exactly the same for Silt Volume as for Original Capacity and all quantities used, except the quantities E, will have the same values.

For each segment, the numbers of the ranges, which are the subscripts in the formula, will generally be taken so that No. 1 is the downstream range, No. 2 the upstream, and Nos. 3 and higher are ranges on tributaries on arms of the lake. In cases where the range on a tributary, or arm of the lake, is nearer parallel to range No. 1 than the upstream range it is taken as No. 2 and the upstream range as No. 3.

It will be observed from the derivation of the general formula, as given below, that, theoretically, there must be at least two ranges in a segment. Where only one appears, as on the end segment of the lake or a tributary arm, No. 2 must be considered as a point at the extreme upper end of the arm. Here then is a range with zero cross-section area, $E_2 = 0$, and zero width, $W_2 = 0$, although A' is not zero. The quadrilateral area A' in this case has one side, W_2, that is zero, and has the shape of a triangle with W_1 as the base and the point of hypothetical range No. 2 as its apex. In this case the formula reduces to,

$$V = \frac{A'}{3}\left(\frac{E1}{W_1}\right) + \frac{A}{3}\left(\frac{E1}{W_1}\right) = \frac{A' + A}{3}\left(\frac{E1}{W_1}\right)$$

The use of the formula for segments having two or more ranges is obvious; the quantities bearing subscripts greater than the number of ranges are equal to zero and vanish.

The Original Capacity and Silt Volume for the segment next to the dam, which has only one range, will be computed by the formula,

$$V = A\frac{E}{W} - V_o$$

where the values of V, A, E, and W, are the same as above the V_o is the volume, in acre feet, displaced by the upstream face of the dam. For concrete dams with vertical or nearly vertical upstream face, $V_o = 0$. For dams with an upstream slope, V_o is computed as follows: For Original Capacity,

$$V_o = \frac{H \quad B \quad L}{174,240}$$

and for Silt Volume,

$$V_o = \frac{L\ (2B - \frac{E}{W}s)\ \frac{E}{W}}{130,680}$$

where L = Length of dam in feet.

B = Width of base of dam at original bottom of reservoir

H = Height of dam, original bottom of reservoir to crestline.

S = Slope of upstream face of dam.

Derivation of the Formula

A formula is desired that will give the most probable values for Original Capacity and Silt Volume when the available data consist

of: (1) The lake area of the subdivision; (2) The width and cross-sectional areas of the ranges, and (3) The points where the thalweg of the streams intersect the ranges. These represent in most cases the extent of data available where the range method is used. In using the general formula, the values of the quantities "h", for ranged Nos. 3 and higher, must be known in addition to the given data. Wherever possible these are to be obtained by plotting original channels from previous maps on present survey maps. Where the location of old channels is not shown on previous maps the points of junction of the tributaries and the main stream must be plotted from judgment, using as guides the shape of the shore line and the points where the thalwegs intersect the ranges as plotted from the range cross-sections. These values of "h", may not be as accurate as desired, but they represent the most probable from the available data.

When an engineer wants the most accurate value of the yardage in a cut, fill or levee from cross-sections, he uses the Prismoidal Formula. This formula gives exact results when the figure is a true prismatoid, and for many figures that are prismoids only by liberal definition. In the problem at hand, the figure is never a true prismoid, but the prismoidal formula makes a good point of beginning.

Consider, first, an imaginary segment with two parallel ranges and shore lines that are straight lines connecting the ends of the ranges. The most probable capacity of this segment can be represented by a prismoid having either rectangles or triangles, with areas equal to the actual areas, for end faces. The width, W, and the depth,

$\frac{E}{W}$ or $\frac{2E}{W}$, vary uniformly from one end face to the other. These prismoids are shown in Figure 1 (a and b)

Figure 1 Equivalent prismoids

Using the notation of the general formula, h', for the perpendicular distance between the ranges, and the subscript, m, for the computed mid-range, the volume of either of these prismoids can be computed as follows by the Prismoidal Formula:

$$V' = \frac{h'}{6}\left(E_1 + 4E_m + E_2\right)$$

where $$E_m = \frac{1}{4}\left(W_1 + W_2\right)\left(\frac{E_1}{W_1} + \frac{E_2}{W_2}\right)$$

which gives $$V' = \frac{h'}{6}\left[E_1 + \left(W_1 + W_2\right)\left(\frac{E_1}{W_1} + \frac{E_2}{W_2}\right) + E_2\right]$$

but $$A' = \frac{h'}{2}\left(W_1 + W_2\right)$$

so that $$V' = \frac{A'}{3}\left[\left(\frac{E_1 + E_2}{W_1 + W_2}\right) + \left(\frac{E_1}{W_1} + \frac{E_2}{W_2}\right)\right]$$

It will be seen from this equation that the average depth of this segment is $\frac{1}{3}\left[\left(\frac{E_1 + E_2}{W_1 + W_2}\right) + \left(\frac{E_1}{W_1} + \frac{E_2}{W_2}\right)\right]$. This volume can be obtained, in the case of Fig. 1 (a) by breaking the prismoid down into prisms, wedges, and pyramids and taking the sum of their volumes; but, in the case of Fig. 2 (b), this method cannot be used because the slope faces are warped surfaces. By resorting to calculus the volume can be proved correct in the latter case.

If the prismoid shown in Fig. 1(b) is ~~changed to~~ the one in Fig. 1(c) it will be bounded by eight triangular, and one quadrilateral, plane surfaces, and by the Prismoidal Formula will have the same volume. That this volume is correct for the new prismoid can readily be proved by breaking it down into three pyramids.

In building up the formula so far, only straight shore lines have been considered and the area used, A', is the quadrilateral area of the general formula. The width of the lake is usually greater between the ranges than at the ranges. This is to be expected because the narrow places are the most practical places to locate ranges. In the large majority of cases, this makes the lake area, the A in the formula, greater than the quadrilateral area, A'. The total volume can be regarded as made up of the volume already established for straight shore lines, Fig. 3(c), plus the volume contributed by the excess area, A-A'. This latter volume might be regarded as equivalent to a wedge-like figure having the maximum depth line as its edge or a pyramid having the depth to the mid-point of the maximum depth line at its altitude. If we consider Fig. 3(c) as the most probable equivalent of the volume for straight shore line and picture the shore line as bent outward in curves the added volume takes the form of the pyramid. A study of the shape of contours in natural reservoirs provides convincing evidence that the pyramid is the form to use rather than the wedge for the excess volume. This

gives for the excess volume,

$$V'' = \frac{1}{3}(A-A') \quad \left(\frac{E1}{W1} + \frac{E2}{W2}\right)$$

This volume added to the volume for straight shore line gives,

$$V = V' + V'' = \frac{A'}{3} \left(\frac{E1 + E2}{W1 + W2}\right) + \frac{A}{3} \left(\frac{E1}{W1} + \frac{E2}{W2}\right)$$

From the form of this equation and from the shape of the figure developed as the equivalent of the most probable volume, it will be seen that, had it been self-evident that this was the shape to use, the above formula could have been derived by taking the sum of the volumes of three simple pyramids.

When tributaries enter the subdivision, or arms of the lake are cut off by ranges, there will be more than two ranges to consider. The formula developed for two ranges is the sum of the volumes of three pyramids with bases equal to the lake area and the two end areas. The altitude of the latter two are automatically provided for in the quadrilateral area, A'. The third and higher numbered ranges will also enter as pyramids, with the range areas as bases and altitude to be determined. Bearing in mind that the shape used in obtaining the most probable volume was an equivalent shape and not the actual shape, a study of natural conditions indicates that the altitude should be the perpendicular distance from the range to the junction of the streams if the junction is inside the subdivision or, if not, to the point where the thalweg of the tributary intersects the lower range.

All the foregoing assumes that ranges Nos. 1 and 2 are parallel, a condition seldom encountered in practice. The only part of the formula

affected by diverging ranges is the expression involving A' as a direct factor. The computation of the error caused by this condition for any segment is impractical because it involves the unknown location of the intersection of the thalweg with an imaginary mid-range. Careful investigation indicates, however, that this error is insignificant up to 10° divergence of ranges and that it tends to compensate in the sum of the volumes of the segments.

CONTOUR METHOD

Primary Control

Primary control is to be established on lakes where adequate previous base maps are not available. Where maps of suitable scale and accuracy can be obtained, surface or subsurface contour mapping should be controlled by frequent reference shots to prominent points shown on the original maps. It is essential that the crest contour as previously mapped should be used, with corrections if necessary, in order that the remapped surface may correspond with the original surface at a level above silt deposits. The original and present contours below crest will both be shown on one final map by different symbols.

Primary triangulation may be used where it is deemed necessary as a base for random or radial soundings used to plot subsurface contours. Because of the time required, however, it should be dispensed with wherever the original maps afford a satisfactory base for accurate location of points.

Surface Contour Mapping

Surface contour mapping is to be used on delta areas where the lower portions of the lake are surveyed by the range method, and on all silt deposits above water at the time of survey where the contour method is used over the entire lake.

Contours must be mapped at not more than 5 foot intervals. On the flatter portions of the silt deposits, elevations should be obtained at sufficiently frequent intervals to map 1-foot contours, which should be drawn on the plane-table sheets in the field. On the final map, only those contours which correspond to the original contours need be shown, that is, if original maps show 5-foot contours, then the same contours on the present surface should be drawn, although on the plane-table sheets the 1-foot contours are also shown.

In surface mapping, stadia traverse and intersection should be used, tying to establish locations. Stadia shots should be taken in all the visible area from each traverse station, and as many separate traverses as necessary, each frequently tied to control points, should be made for thoroughly covering the surface.

Three-point location should not be resorted to except in special cases where time required for traverse or intersection would be excessive. No traverse should be run from a three-point location.

Subsurface Contour Mapping

Several methods may be used for obtaining accurate location in subsurface contour mapping. Each will doubtless be found of advantage at one time or another during the course of subsequent surveys. It is a prime requisite, of course, that an adequate number

of accurately located soundings be taken to afford a sure basis for interpolating contours on an invisible surface. Naturally the more irregular the silt terrain, the more soundings required and conversely, the flatter the fewer.

(1) A radial fan of lines covering a section of the lake may be drawn on the plane-table sheet at any previously established station at suitable angles of 10° or 15° apart and stake out on the ground by setting pegs on the direction of each line at the water's edge in front of the instrument. Cut-in stations are established by stadia at positions so that suitable inter-sections may be obtained on all radial lines. The rear target is then set on the original station and the front target is moved from peg to peg on the several radial lines as a boat moves back and forth across the lake successively on these lines. Soundings are located on the plane-table at a cut-in station by a direction line drawn to cross the radial line on which the boat is moving.

(2) A control network of stations covering both banks of the lake may be established. From alternating stations on each bank radial lines are plotted on the plane-table sheets at suitable angles apart, usually 10° beginning with the orientation line toward another station in the previously established net. Adjacent stations in the net may serve as cut-in points. Instead of targets, a transit is set up at the apex of a set of radial lines and oriented on one end station of the radial pattern. The boat moves along this initial line directed by signals from the transitman. The plane-table operator at the cut-in stations signals for soundings. As this sub-range is complete, the transit is turned 10° and the boat directed along the second sub-range.

The process is continued until this radial pattern of sub-ranges is completed, whereupon the transit is moved to the apex of an adjoining radial pattern on the opposite shore to continue the soundings.

(3) The system of transit and plane-table operated at adjacent stations in a previously established net may be used without establishing a radial pattern of ranges. In this case, the boatman may direct progress of his movements, and on his signals an angle is read on the transit with each sounding and a direction line drawn on the plane-table. This permits boat movements in a zig-zag course under conditions that permit entry only along certain channels.

(4) The underwater surface may be contoured by establishing ranges sufficiently close together in the same manner as in normal range work. This is sometimes advisable and time-saving where the silt surface is especially flat and even.

(5) Under unusual conditions and in quiet water, sounding positions may be located from stadia rod held firmly in the center of the boat. This method should be used only in emergencies, however, as it is especially susceptible to error.

Computation of Original Capacity and Silt Volume

Where an original contour map is available and thesilt surface has been subsequently remapped on the same scale and contour interval, the following modified Prismoidal formula will be used for computing the original capacity and silt volume between two adjoining contours. The formula may be used for either a segment of the lake bounded by one or more ranges and intervening stretches of shore line or for the lake as a whole bounded only by the dam and shoreline.

$$V = L/3\ (A + \sqrt{AB} + B) \text{ acre feet}$$

Where V = Original capacity on silt volume in acre feet.

L = Contour interval in feet. In the lowest prismoid, L is the vertical distance between the lowest contour and the lowest point in the bottom of the reservoir.

A = Area, in acres of the original lower contour for original capacity of difference between the areas of the original lower contour and the present lower contour for silt volume. In the lowest prismoid A equals zero for both original capacity and silt volume.

B = Area, in acres, of the original upper contour for original capacity or difference between the areas of the original upper contour and the present upper contour for silt volume.

The formula is applied progressively to the prismoids, or volumes between the contours, beginning with the prismoid between the lowest contour and the bottom of the reservoir. The sum of three volumes will give the desired total.

This method of computation has the advantage of establishing distribution of original capacity and total sediment in the vertical as well as areal plan of the reservoir, which is of great practical importance from the viewpoint of reservoir utility.

FURTHER COMPUTATIONS

The following additional computations should be made and the results tabulated, as shown in the Statistical Summary Table at the end of the following section on Preparation of Final Reports:

1. Original area at crest stage.
(Sum of all surface areas planimetered from original base maps or remapped original crest line contour. Previous estimates are usually unreliable) Acres.

2. Present area at crest stage (Sum of all surface areas to present crest line contour. The present area should be less by the amount of delta fill to and above crest, and greater by the amount of bank erosion) Acres.

3. Original storage capacity (In range method, sum of capacities of various segments. In contour method, obtained by planimetering original base maps. Previous estimates are usually unreliable) Acre-feet.

4. Present storage capacity (In range method sum of original capacity of various segments less sum of sediment deposited) Acre-feet.

5. Storage per square mile of drainage.

$$\text{Original} = \frac{\text{Acre-feet of original storage}}{\text{Square miles of drainage}} \text{ (Acre-feet)}$$

$$\text{Present} = \frac{\text{Acre-feet of present storage}}{\text{Square miles of drainage}} \text{ (Acre-feet)}$$

Compute to second decimal place.

6. Delta deposits (Sum of all volume computations of delta deposits in various segments) (Acre-feet)

7. Bottomset beds (Sum of all volume computations of bottomset beds in various segments) (Acre-feet)

8. Total Sediment (Sum of 6 and 7) (Acre-feet)

9. Accumulation per year (average) = $\frac{\text{Total sediment}}{\text{years}}$ (Acre-feet)
Compute to second decimal place. Years should be determined to a fraction representing nearest month when filling began.

10. Accumulation per year per 100 square miles of drainage area =

$$\frac{\text{Accumulation per year (determined in 9) x 100}}{\text{Square miles of drainage area.}} \text{ (Acre-feet)}$$

Compute to second decimal place.

11. Accumulation per year per acre of drainage area=

$$\frac{\text{Accumulation per year (determined in 9) x 43560}}{\text{Square miles of drainage area x 640}} \text{ (Cubic-feet)}$$

Compute to second decimal place.

12. Or, assuming average weight of silt is 100 pounds per cubic feet =

$$\frac{\text{Cubic feet (determined in 11) x 100}}{2000} \text{ (Tons)}$$

13. Percentage loss of original capacity per year =

$$\frac{\text{Accumulation per year (acre-feet determined in 9)}}{\text{Original capacity (acre-feet determined in 3)}} \text{ x 100 (\%)}$$

Compute to third decimal place.

14. Percentage loss of original capacity to date of survey.

$$\frac{\text{Total sediment (acre-feet determined in 8)}}{\text{Original capacity (acre-feet determined in 3)}} \text{ x 100 (\%)}$$

NOTE KEEPING

Field notes should be kept in standard engineering field books which may be obtained on requisition from the Washington office. All notes should be neatly and uniformly printed. The flyleaf in the front of each notebook should contain a legend after the following pattern:

Sedimentation Survey

of

Boomer Lake,

Stillwater, Oklahoma.

June 4-18, 1935.

Sedimentation and Hydraulic Studies

Soil Conservation Service
U. S. Department of Agriculture

Field Book No. 1 of 3

Thomas L. Kesler,
Chief of Party.

The same legend should appear on the front cover of the notebook.

Immediately following the flyleaf should be a complete index of all notebooks of the survey if more than one book is used. Unless only one book is used there should follow a separate index of the first notebook, and each succeeding notebook should have an individual index.

Following the index of the first notebook, all general description of the reservoir, namely, the information required in the reservoir inventory report, should be given. Also any additional information of importance regarding the survey.

Notes of various types such as triangulation, stadia traverse, range sounding, etc.,shall be segregated on separate pages but may be given in any order in a properly indexed notebook. Notes shall conform to standard engineering practice with care being taken that sounding and spud notes contain adequate legend for use by engineers unfamiliar with this type of survey. Weather conditions and duties of each engineer should be recorded for each day.

Planimeter measurements and computations of areas and capacities should be recorded in the last notebook following field notes. All factors scaled from maps and sections such as range widths and lengths of lines erected for height of pyramid in sidearm computations must be recorded.

No field book should contain notes on more than one lake.

SURVEY MONUMENTS

All triangulation stations, range ends, and other important survey points will be marked by substantial concrete monuments set

two to three feet in the ground. Elevations will be determined on the top center of each monument which will be marked with the station number and properly recorded in the field book.

PREPARATION OF FINAL REPORTS

In the preparation of final reports on each reservoir investigation, the outline below should be followed as rigidly as possible in order to insure uniformity of treatment in the several parties. It will not, of course, be possible to obtain all the information suggested here for each report, nor will a place be found in this outline for every class of information that may be of local importance. It should be borne in mind that the principal objective in these reports is to present a systematic, clear, and concise arrangement of data and observations in uniform style. Tabulations should be used as much as possible, so long as they are readily understandable even to casual inspection.

SEDIMENTATION IN LAKE

TOWN , STATE

GENERAL INFORMATION

Location: State:

County: (or Counties. Give also Sections, Ranges and Townships where possible)

Distance direction from nearest city:

Drainage and Backwater: (Give drainage on which dam is located and all important tributary streams on which backwater is impounded).

Ownership:

Purpose served: (If dual purpose as water supply and power, compare use for each purpose).

Description of dam: (Give type material of construction, length, height, thickness, type and elevation of spillway, and any unusual features such as flood gates, mud gates, material on which constructed, etc.)

Date of completion: (To nearest month, also average data of survey and total age to date of survey:)

Length of lake: Original: (From dam to head of backwater. If there is more than one major arm of the lake, give distances on each arm)

Present: (Or amount shortened by delta deposits on the several arms)

Shortening:

Area of lake at crest stage: Original:

Present:

Reduction

Storage capacity at crest level: (Acre-feet. If a water-supply reservoir also, give gallons. State whether capacity determined by this survey, or as original survey or estimate)

	Acre-feet	Gallons
Original		
Present		
Loss due to silting		

General character of reservoir basin: (General discussion of physical characteristics of reservoir basin)

Former silt surveys: (Give in detail all information obtainable on former silt surveys, including type of survey, date, name of persons or agency making survey, and results obtained by survey).

Area of watershed: (Square miles or acres)

General character of watershed: (Brief treatment of each of the following topics, sufficient to give a generalized picture of watershed conditions)

Geology
Topography
Soils
Erosion conditions
Land-Use

Forests
Pasture or range
Cultivated
Crops

Mean annual rainfall: (Weather Bureau Reports, Soil Survey Reports, SCS regional office data).

Inflow into reservoir: (U.S.G.S. gaging records where available).

Evaporation: (Available only in certain places. Often determined by owners of reservoir).

Draft on municipal reservoirs: (Usual daily or monthly draft. Season of greatest use and draft during this period).

Power development: (Installed power equipment; number of units, rating of each and of plant as a whole, h.p.K.w.,Kva; operating head under full reservoir; ordinary daily or seasonal draw-down of reservoir below dam crest level; draft in cubic feet per second under full plant operation with full reservoir).

Irrigation: (Annual draft or amount of water used during the whole growing season in acre-feet; either from records or from number of acres irrigated multiplied by usual depth in feet of water applied to typical crops during a full season).

HISTORY OF SURVEY

Give dates of survey periods, name of party and party chief and other personnel.

Summarize work done, as a number of triangulation stations, number of ranges, miles of shore line mapped, acres contoured. Refer to general method used in survey. Give mapping scale and description of previous base maps available.

Description of any local peculiarities that necessitated methods not covered in general instructions. Complete description of any methods used that did not conform to general standards.

ACKNOWLEDGMENTS

Acknowledge all help received from outside sources in making this survey. Do not acknowledge help of SCS regional officer in official capacities, but personal help of members of the staff, not in line with official duties, may be acknowledged.

CHARACTER, DISTRIBUTION AND ORIGIN OF SEDIMENT

A general discussion of all features of sedimentation in the reservoir, and their relation to soil, slope and climatic and land use conditions, in the tributary watershed. The development and treatment in this section, which is really the summary and interpretation of observations made during the survey is left to the judgment of the responsible field personnel.

This section should include among other things, however, a systematic presentation of findings by written description and graphs, bringing out quantities and distribution of deposits.

1. By ranges and areas.
2. By classes, i.e. delta deposits and bottomset beds.
3. By contour interval for each successive elevation if complete topographic map method is available.
4. By average and specific depths of sediment in different parts of the lake.

The character of the sediment as to texture, color, and consistency in different parts of the lake should be described and the relation of these features to the character of the drainage area should be discussed insofar as the drainage area is known. Treatment of all special features studied, such as wave erosion, mass movements of silt, etc. should be discussed in this section.

All interpretations and conclusions that are drawn from the

completed study and digest of silting conditions should be presented in one or two final paragraphs.

COMPUTATIONS

(Tabulations should be arranged under the following headings when end-area calculations are used).

Range Surveys

Ranges

Range No.	Width, feet	Original end-area (present water plus silt)	Present end-area (water)	Silt end-area

Surface Areas

Segment No.	Square ft. surface	Acres	Ranges bounding each segment
Totals			

Segment Volumes

Segment No.	Original Capacity (Acre-feet)	Present Capacity (Acre-feet)	Silt (Acre-feet)
Totals			

Contour Surveys

Areas Enclosed by Contours

Contour Elevation	Original Area Acres	Present Area Acres	Difference Acres

Capacities by Contour Intervals

Bounding Contours	Original Capacity Acre-feet	Present Capacity Acre-feet	Silt Acre-feet
Totals			

Capacities to Each Contour

Elevation	Original Capacity Acre-feet	Present Capacity Acre-feet

Table 1. - Statistical summary of data relating to

	Quantity	Unit
Age:[1]		
Watershed:		
Total area		
Reservoir:		
Original area at crest stage		
Present area at crest stage		
Original storage capacity		
Present storage capacity		
Original storage per square mile of drainage area		
Present storage per square mile of drainage area		
Sedimentation:		
Delta deposits		
Bottomset beds		
Total sediment		
Accumulation per year average		
Accumulation per year per 100 square miles drainage area		
Accumulation per year per acre of drainage area		
Or, assuming average weight of 1 cubic foot of silt is 100 pounds		
Depletion of storage:		
Loss of original capacity per year		
Loss of original capacity to date of survey		

1/ Date storage began: Date of this survey:

Preparation of Maps, Illustrations and Supplemental Material

(1) A general map of the lake showing shore line and other contours, all triangulation and secondary stations, ranges and range ends should be prepared for planimeter measurements. This map should be labeled with range widths and acreage within segments. Where original maps of suitable accuracy are available all surveying data and legend may be drafted on these providing no confusion will arise from crowding of lines. Where only planetable sheets are available, a single composite map must be drafted.

All maps will be redrafted in the Washington office. Therefore, maps submitted from the field need follow only the requirement that all information thereon be accurate, legible and subject to no confusion of detail.

(2) A compact systematic folio, preferably bound in covers, of range cross-sections and other graphs will be submitted.

(3) Field notebooks properly prepared as outlined above, will be submitted with the final report.

(4) Planetable sheets properly numbered and labeled for identification will be forwarded to the Washington office for filing.

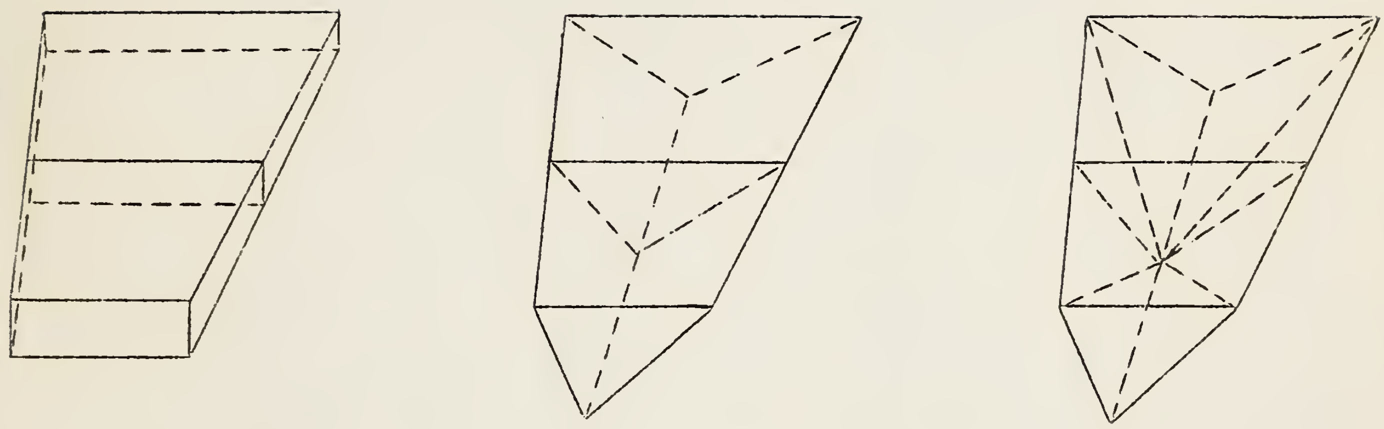
(5) All film exposed in the field will be developed in the Washington office and a set of prints supplied to the field for inclusion in reports. (Additional prints available on request). All exposed features of sedimentation should be amply illustrated with photographs in the final report.

Public Relations

Field personnel must be courteous and considerate in all public relations, particularly in relation to management of reservoirs who may be approached for information and cooperation in connection with these studies. Scrupulous care must be taken with regard to confidential information, and in safeguarding and returning promptly any maps or other data taken under agreement as a temporary loan.

It is permissible to let the public know the general identity of the part and nature of the assignment, that is, a field party of the Soil Conservation Service, Department of Agriculture, engaged in study of silting of reservoirs and related watershed conditions. It may be agreed that the work is new, interesting and apparently quite important.

It is not desirable or permissible, on the other hand, to make casual conversational matter of factual findings of these investigations or of information concerning specific reservoirs that may be obtained in line of duty. The public will be more favorably impressed and more cooperative if field personnel reserve such information strictly for official reports. This is, of course, only a re-statement of usual professional ethics relating to official information concerning private business and property.



(a) (b) (c)

Fig. 1 Equivalent prismoids